MAY 21 1947

ARR No. 4H26

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
August 1944 as
Advance Restricted Report 4H26

AN EXPERIMENTAL INVESTIGATION OF THE THRUST AND TORQUE PRODUCED BY PROPELLERS USED AS AERODYNAMIC BRAKES

By William S. Hedrick and William M. Douglass

Ames Aeronautical Laboratory
Moffett Field, California

NACA

WASHINGTON

NACA ARR No. 4H26

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

AN EXPERIMENTAL INVESTIGATION OF THE THRUST AND TORQUE PRODUCED BY PROPELLERS USED AS AERODYNAMIC BRAKES

By William S. Hedrick and William M. Douglass

SUMMARY

This report presents the results of a wind-tunnel investigation of propellers operating at negative thrust. Negative-thrust characteristics of two- and four-blade single propellers and four- and eight-blade dual propellers were determined. Flight conditions were simulated by installing the propellers in a powered model of a high-speed airplane.

Application of the results to several flight problems illustrates the use of the presented data and indicates the utility of a constant-speed reversed-pitch propeller as a device to obtain speed control. Comparison of a constant-speed reversed-pitch propeller with a typical dive flap shows that the propeller can produce a higher average deceleration and a lower terminal velocity.

INTRODUCTION

The need for an adaptable speed control for airplanes to meet the requirements imposed by weight, speed, and tactical use of present-day aircraft is becoming increasingly evident. With the advent of a quick-reversing mechanism for propellers, the reversed-pitch propeller presents a possible solution to many braking problems.

Some of the existing means of speed control that have not proved entirely satisfactory are spoiler flaps and flaps extended to negative angles. These brakes are seriously limited in application. They are of no use for control in landing, since they require relatively high forward speeds to be effective. Furthermore, a flap that produces enough drag to be suitable for braking usually causes severe buffeting. The use of a reversed-pitch propeller as a brake does not entail these undesirable features, but the effects on longitudinal and lateral stability and on control are yet to be investigated. Further, the high negative thrust load of this propeller will impose structural problems that must be considered.

The present investigation was made to determine the thrust characteristics of two- and four-blade single propellers and of four- and eight-blade dual propellers in the region of negative thrust. It is also the purpose of this report to show that reversed-pitch propellers afford a means of speed control that surpasses those now in use.

APPARATUS AND METHODS

Propellers

All of the propellers tested were of Hamilton Standard Conventional form, 6457A-6, embodying NACA 16-series sections throughout. The blade-form characteristics are given in figure 1.

Both the single and dual propellers were mounted in the dual spinner (figs. 2 and 3), the single propeller being placed in the rear hub. The front hub was keyed to the motor shaft and drove the rear hub through reversing gears. Some details of the dual spinner appear in figure 4.

Model

The propellers were installed in a powered model of a midwing, single-engine, two-place airplane. The airplane is of a type that would require some additional means of speed control because of its tactical purpose. Some pertinent dimensions are given on the three-view drawing (fig. 5).

Motor

The propellers were driven by a Byron-Jackson variable-speed, four-pole, squirrel-cage induction motor rated at 110 horsepower at 10,000 rpm.

Measurements

The power developed by the motor was determined from wattmeter readings of the power input and from a motor calibration. A constant ratio of voltage to frequency was maintained throughout the test to insure that the calibration would be applicable for every operating condition.

The net thrust or drag was measured by the drag balance.

Corrections

Due to the method of obtaining dual rotation, gear losses were encountered. At the time of the motor calibration, the gear losses at various speeds and loads were determined. This loss was applied, as a correction, to the power developed by the motor.

The effective velocity for a propeller operating in a wind tunnel is not the same as the test-section datum velocity, due to the constraint of the airstream by the tunnel walls. To determine the "equivalent free airspeed," a correction based on Glauert's treatment as found in reference 1 was applied.

Test Procedure

In the tests, airspeed was varied while the propeller rotational speed was held constant. The propeller rotational speed was set at a value limited either by power available or by a blade-tip Mach number of 0.4, and the airspeed was then varied, in suitable steps, from 30 to 370 feet per second. Both the rotational speed and the airspeed were then reduced and a similar procedure followed until the desired range of advance ratios was covered.

SYMBOLS AND COEFFICIENTS

The symbols and coefficients used in this report are defined as follows:

C_Q	torque coefficient $\frac{Q}{\rho n^2 D^5} = \frac{P}{2\pi\rho n^3 D^5}$
C_T	thrust coefficient $(T/\rho n^2 D^4)$
T_c	thrust coefficient $(T/\rho V^2 D^2)$
V/nD	advance ratio
Q	torque absorbed by the propeller, foot-pounds
P	power absorbed by the propeller, foot-pounds per second
V	airspeed, feet per second
n	propeller rotational speed, revolutions per second
D	propeller diameter, feet
ρ	mass density of air, slugs per cubic foot
T	effective thrust; the measured thrust of the propeller-model combination plus the drag of the model measured without the propeller (propeller thrust minus incremental drag due to the slipstream)
β	propeller-blade angle at the 75-percent radius
W	weight of the airplane, pounds
S	wing area, square feet
C_D	airplane drag coefficient
ΔC_D	increment of drag coefficient
g	gravity constant, feet per second per second
a	rate of change of velocity with time, feet per second per second
t	time, second
s	distance, feet

RESULTS AND DISCUSSION

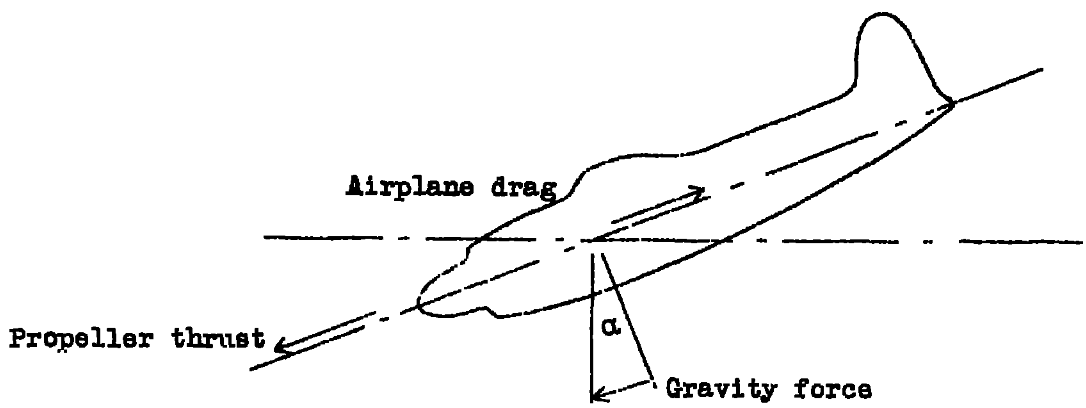
It is well known that data derived from model-propeller tests at low Reynolds numbers are not applicable to calculations of full-scale performance, nor is it possible to extrapolate, with accuracy, model results to full scale. However, the data given in this report should give an indication of full-scale properties and will serve to extend previous tests of propellers at negative thrust.

The propeller data have been presented in a form to be used for the calculation of flight problems of airplanes equipped with constant-speed propellers. Curves for the four propellers showing the variation C_T with V/nD and T_c with nD/V with lines of constant-torque coefficient are shown in figures 6 to 9. From these curves, the negative-thrust coefficients may be determined for an airplane in decelerated flight while operating at a constant-power coefficient. With the use of the additional curves showing lines of constant blade angle in place of constant-power coefficient (figs. 10 to 13) all propeller data that may be required are obtainable. This form is also of value for braking propellers operating at a single negative blade angle. Calculations for this propeller require a second approximation of the advance ratios to account for the variation of revolutions per minute with change in torque coefficient that results from the pitch reversal and the subsequent changes in velocity. The revolutions per minute variation with torque for the engine of the airplane in question must be available.

An examination of the data at a given blade angle reveals a variation of propeller characteristics with solidity. Above values of $V/nD = 2$, thrust varies proportionally with number of blades. However, for lower advance ratios, the thrust developed by the eight-blade dual propeller is not proportionally greater. It is noteworthy that the torque coefficient changes in the same manner, indicating that the reduction in thrust coefficient is a propeller effect, not a change in results due to some unique characteristic of the model. The effect of type of rotation is shown in figure 14.

An equation showing the relation between velocity and deceleration is desirable for applying the data to the solution of flight problems.

For an airplane diving at a constant angle,



the decelerating force is

$$F = (\text{airplane drag}) - (\text{propeller thrust}) - (\text{gravity force}) \quad (1)$$

where

propeller thrust = $T_c \rho V^2 D^2$ or $C_T \rho n^2 D^4$

airplane drag = $1/2 \rho V^2 S C_D$

gravity force = $W \sin \alpha$

Then

$$F = -\left\{\begin{matrix} T_c \rho V^2 D^2 \\ \text{or} \\ C_T \rho n^2 D^4 \end{matrix}\right\} + 1/2 \rho V^2 S C_D - W \sin \alpha \quad (2)$$

Now

$$F = -\frac{W}{g} a \quad (3)$$

Equating (2) and (3) gives

$$-\frac{W}{g}\,a = -\begin{Bmatrix} T_c\rho V^2D^2 \\ \text{or} \\ C_T\rho n^2D^4 \end{Bmatrix} + 1/2\rho V^2SC_D - W\sin\alpha$$

or

$$a = -\frac{g}{W}\left[-\begin{Bmatrix} T_c\rho V^2D^2 \\ \text{or} \\ C_T\rho n^2D^4 \end{Bmatrix} + 1/2\rho V^2SC_D - W\sin\alpha\right]$$

Certain factors will remain constant for a constant-speed propeller: D, n, W, S, g, C_D, and ρ. (For a first approximation C_D and ρ may be assumed to be constant.) By choosing several values of advance ratio covering the operational range, the corresponding thrust coefficients may be found from the curves (figs. 6 to 9) for operation at the desired torque coefficient. It is then possible to find the relation of a to V.

In a flight problem it may be desirable to find any one of the variables of kinematics; velocity, deceleration, distance, and time. Given velocity and deceleration to find distance and time. The solutions of these variables may be analytical or graphical.

To find time

$$dt = \frac{dV}{a}$$

To solve analytically it is necessary to have

$$a = f(V)$$

then, integrating

$$t_{o-x} = \int_{V_o}^{V_x} \frac{dV}{f(V)}$$

Otherwise the solution must be graphical.

Plot the variation of $1/a$ with V.

$$\text{The area} = \sum_{V_o}^{V_x} \frac{1}{a} \times \Delta V = t_{o-x}$$

Similarly, to find distance

$$ds = Vdt$$

also

$$dt = \frac{dV}{a}$$

Therefore

$$ds = V\,\frac{dV}{a}$$

Given

$$a = f(V)$$

then, integrating

$$s_{o-x} = \int_{V_o}^{V_x} \frac{VdV}{f(V)}$$

Or graphically:

Plot the variation of $\frac{V}{a}$ with V

$$\text{The area} = \sum_{V_o}^{V_x} \frac{V}{a} \times \Delta V = s_{o-x}$$

As the airplane decreases in speed, the lift coefficient must be increased, resulting in a change in drag coefficient. For a closer approximation, this increase of drag coefficient with decreased speed must be considered. Also, if the maneuver of the airplane results in a considerable change in altitude, for more exact calculations, mass density should be corrected for altitude.

To investigate the merits of propellers operating at negative thrust as compared to dive flaps, an analysis, using the described methods, was made of an airplane in a 60° dive and with an initial airspeed of 400 miles per hour. The comparison was made for three power loadings at the same propeller diameter and rotational speed and for four values of ΔC_D due to dive flaps. To show the effect of diameter upon the braking effect of propellers, a larger diameter propeller and a power loading comparable with one of the above cases was chosen. It was necessary to modify the true increase in deceleration developed by the larger propeller diameter by decreasing the propeller rotational speed to keep within the critical tip speed.

The data used for this comparison were:

Four-blade single propeller

Power loadings = 5, 10, 20 pounds per brake horsepower

W = 14,000 pounds

D = 12 feet

n = 25 rps

S = 375 square feet

ρ = 0.00205 (assumed constant) at 5,000 feet

C_D = 0.023 (assumed constant)

$\alpha = 60^\circ$

ΔC_D = 0.100, 0.125, 0.150, and 0.200

To show the effect of diameter of the propeller

D = 13 feet

Tip speed = πnD = 970 feet per second

Power loading = 5 pounds per brake horsepower

The results are presented in curves showing the relation of deceleration to velocity (fig. 15) and velocity to time (fig. 16). Figure 15 shows the small effect of changes in power on the magnitude of the deceleration as compared to the effect of a change in propeller diameter. The selection of a propeller diameter might well be influenced by this increase in deceleration. The curves for the dive flaps show such undesirable characteristics as rapidly decreasing effectiveness with decreasing airspeed and a correspondingly high terminal velocity. Although it is possible to develop a ΔC_D of 0.200 with dive flaps, the buffeting, loss in control-surface effectiveness, and high wing moments at high velocity often render the flaps unusable. The lower terminal velocity and the lower maximum deceleration of the propeller as compared to dive brakes giving the same average deceleration show the advantage of the propeller over the dive flap.

One of the most important uses of the constant-speed reversed-pitch propeller would be to obtain additional deceleration when landing. To illustrate, calculation of landing run with and without the negative thrust of the propeller has been made for a typical case. The airplane assumed is a heavy, multiengine transport or bomber, equipped with tricycle landing gear, landing on a concrete runway.

These data were used:

Four, three-blade propellers

Normal rated power = 8000 brake horsepower

Touchdown speed = 120 miles per hour

W = 95,000 pounds

W/S = 68 pounds per square foot

D = 16 feet 7 inches

n = 14 rps

C_D = 0.0975

The airplane is assumed to approach the runway at 0.4 normal rated power. At the instant of contact, the propellers are reversed at constant power and full wheel brakes (coefficient of friction = 0.26) are applied.

Curves of "the variation of a with V" and "the variation of s with V" have been plotted (figs. 17 and 18) for wheel brakes operating, braking propellers, and both wheel brakes and braking propellers. Figure 18 shows a landing run of 2635 feet for wheel brakes alone and 1800 feet for wheel brakes and braking propellers. This is a saving of 32 percent of the landing run due to the use of constant-speed reversed-pitch propellers. This reduction would be still greater if the surface of the runway had lower friction coefficients as in the case of a wet runway.

Another illustration of the use of the constant-speed reversed-pitch propeller is given. The case considered is that of a fighter airplane overtaking a bomber and increasing the firing time by braking with the propeller.

Curves for the variation of distance with time are given in figure 19.

These data were used:

W = 8600 pounds

P = 1266 brake horsepower at 27,000 feet

D = 11 feet 2 inches (four-blade single propeller)

S = 233.2 square feet

n = 23.85 rps (propeller)

Constant lift (level flight)

C_D variable with speed

The maneuver would consist in approaching the bomber at maximum speed until within firing range. Propeller pitch would then be reversed to reduce the speed and obtain longer firing time. For comparison, the same calculation was made for split-flap-type aerodynamic brakes developing a $\Delta C_D = 0.126$. The pursuit airplane was assumed to open fire at 1000 feet and break off contact at 50 feet. By starting the curve for the bomber at 950 feet on the "S" abscissa, the point on the "t" ordinate corresponding to the intersection of the pursuit and bomber curves gives the total firing time. It is apparent that reversed-pitch propellers give a greater increase in firing time than the split flap in this case. This advantage will be enhanced at lower pursuit speeds.

CONCLUSIONS

The results of the experimental investigation show that constant-speed reversed-pitch propellers possess aerodynamic characteristics that should make them excellent aerodynamic brakes. They are capable of producing large negative thrusts, and the variation of thrust with speed (approx. linear) is more desirable than that developed by dive flaps. They produce comparatively large values of negative thrust even at low airspeeds, and therefore are of particular utility in decreasing the landing run and in maneuvering aircraft on the ground. Since from this thrust study the use of propellers as aerodynamic brakes seems most promising, it is believed that the effects of so using the propellers on the airplane stability and control should be investigated. Such an investigation is now being made.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

REFERENCE

1. Glauert, H.: The Elements of Aerofoil and Airscrew Theory. Cambridge University Press, 1926.

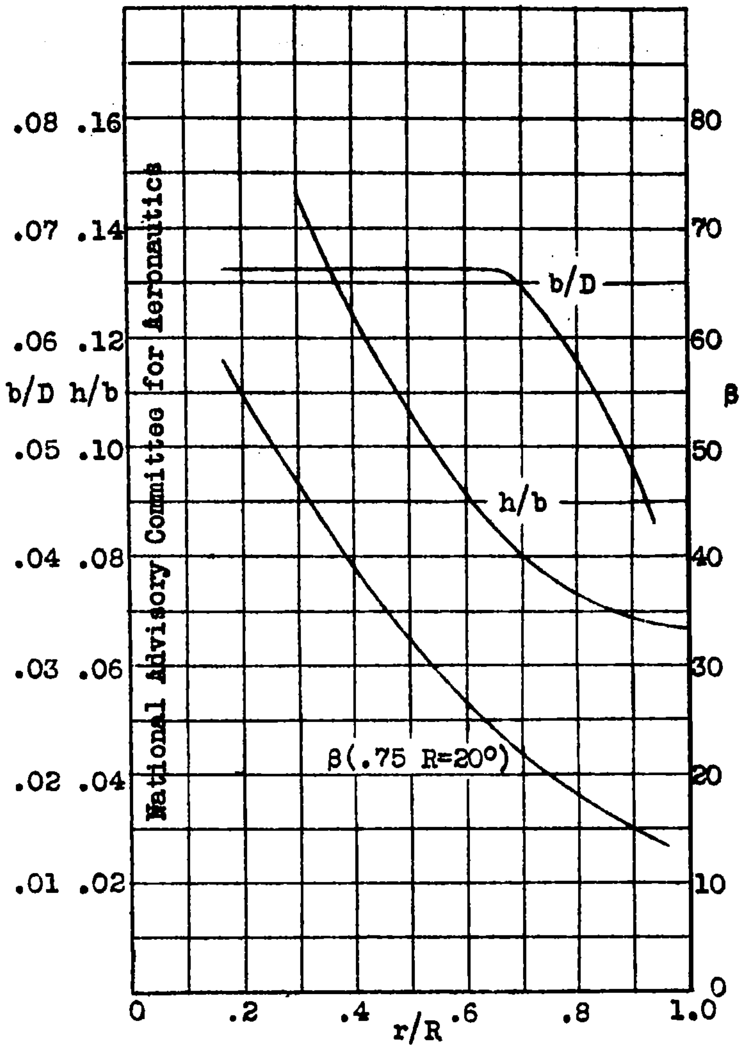


Figure 1.- Blade-form curves for the Hamilton Standard conventional propellers, 6457A-6. D, diameter; R, radius to tip; r, station radius; b, section chord; h, section thickness; β, blade angle.

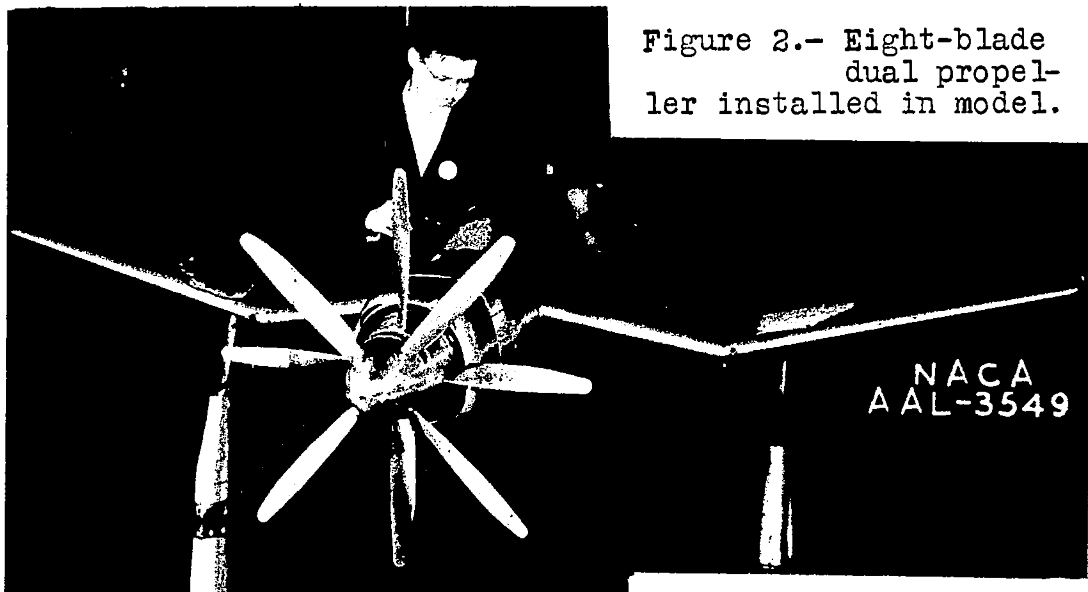


Figure 2.- Eight-blade dual propeller installed in model.

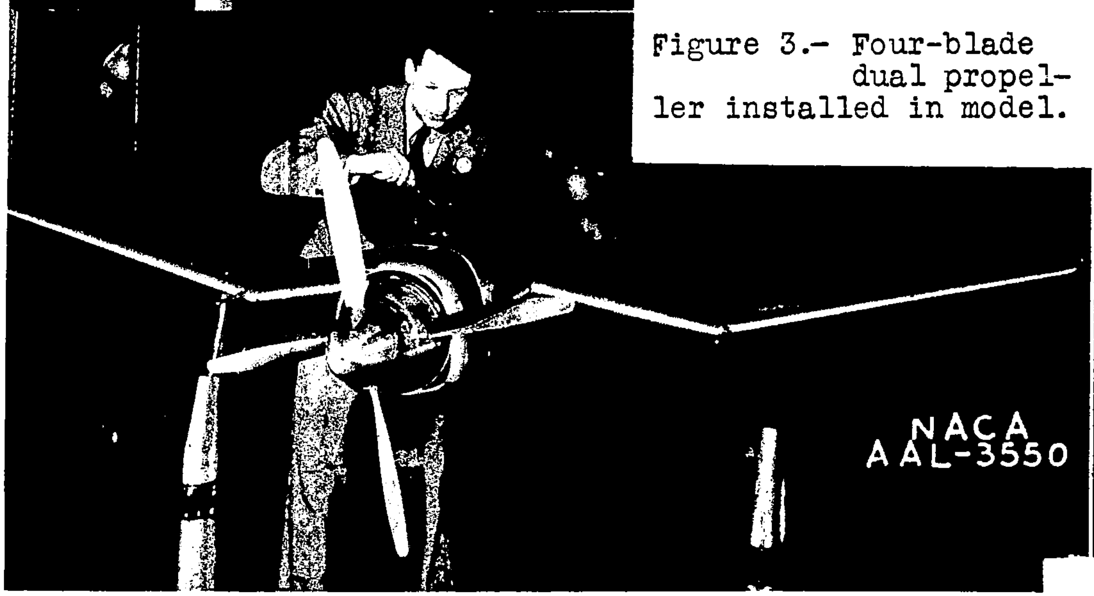
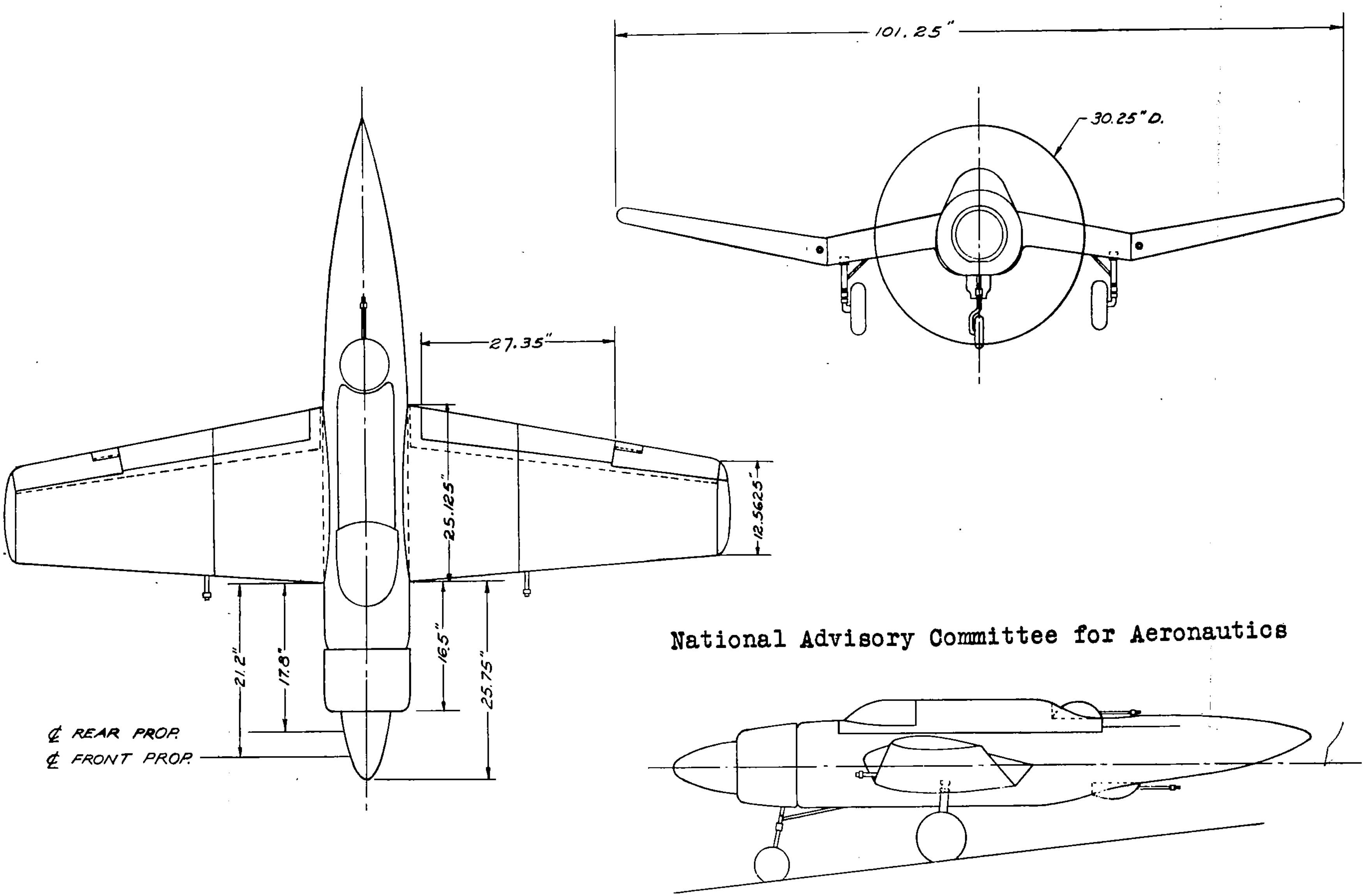


Figure 3.- Four-blade dual propeller installed in model.

Figure 4.- Details of dual spinner.



National Advisory Committee for Aeronautics

Figure 5.- Three view sketch of the model.

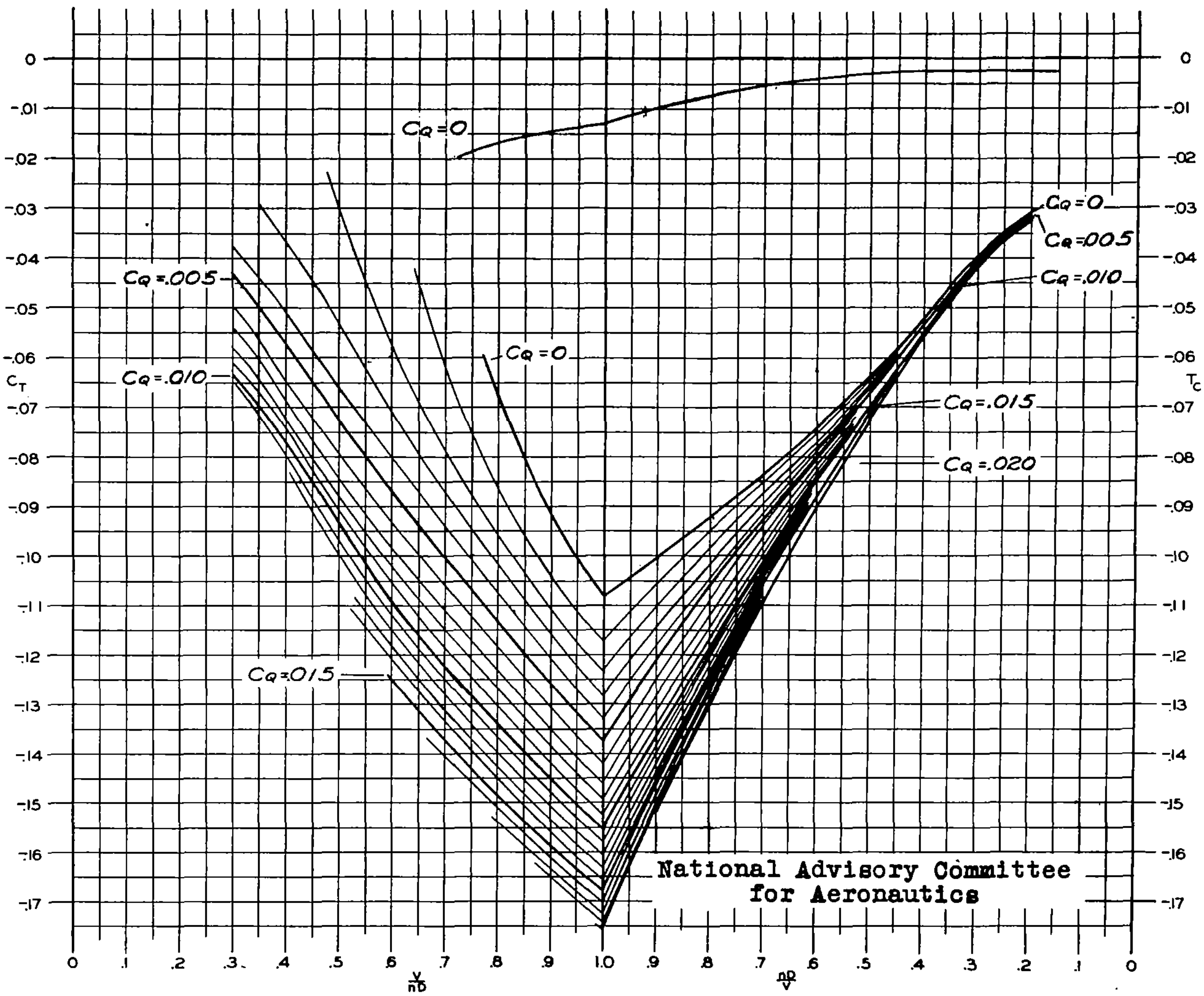


Figure 6.- Negative thrust coefficients at constant torque coefficients for the two-blade, single propeller.

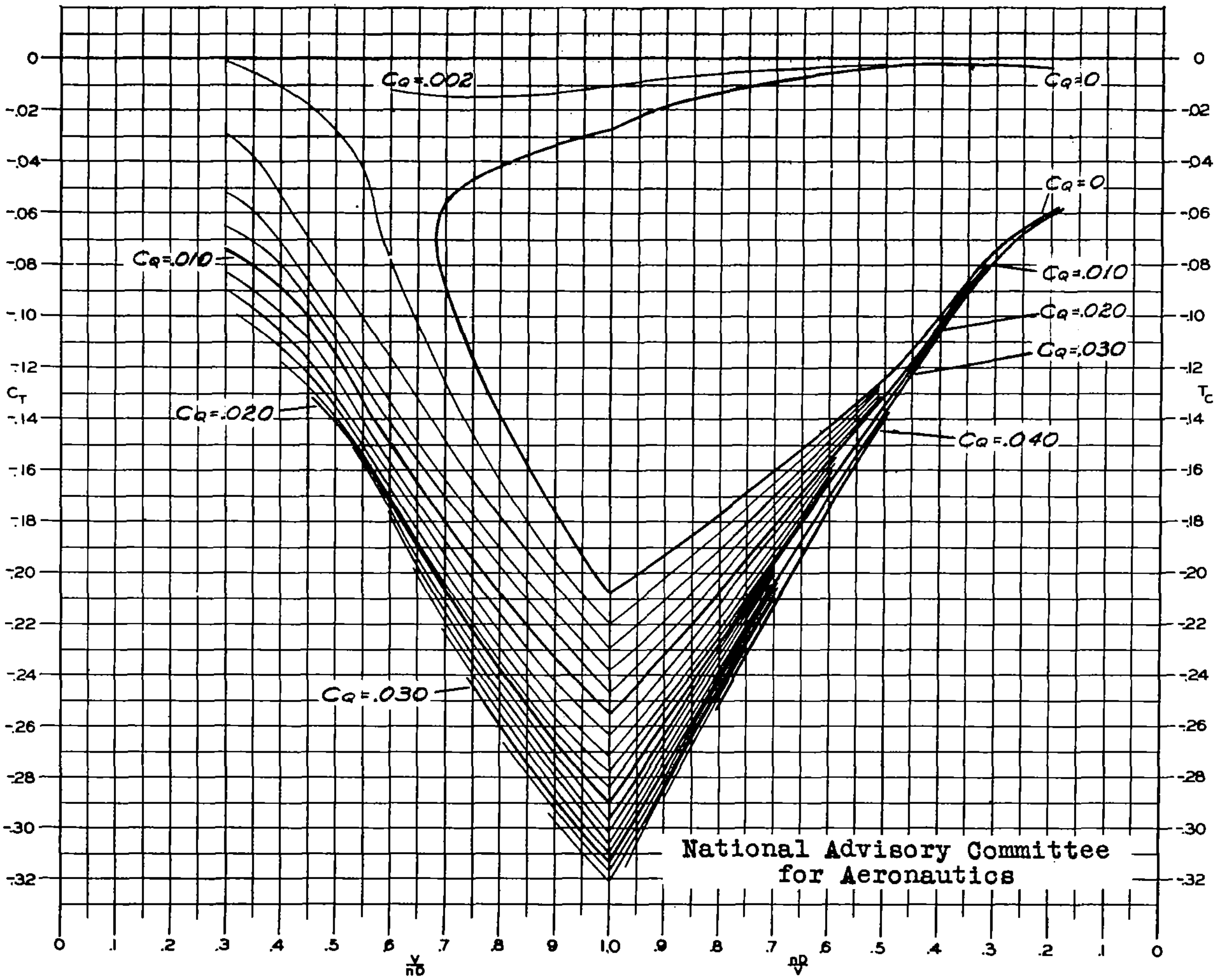


Figure 7.- Negative thrust coefficients at constant torque coefficients for the four-blade, single propeller.

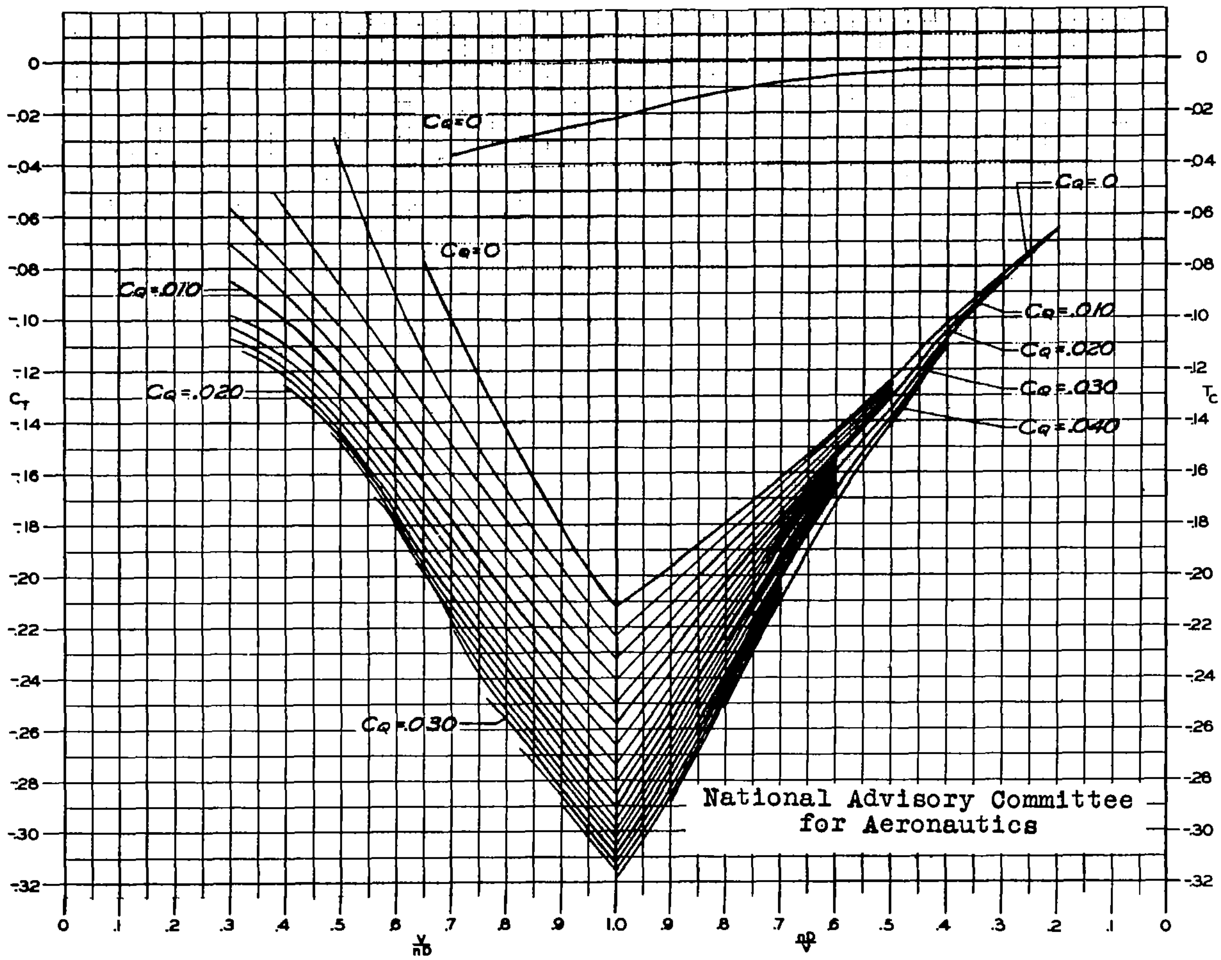


Figure 8.- Negative thrust coefficients at constant torque coefficients for the four-blade, dual propeller.

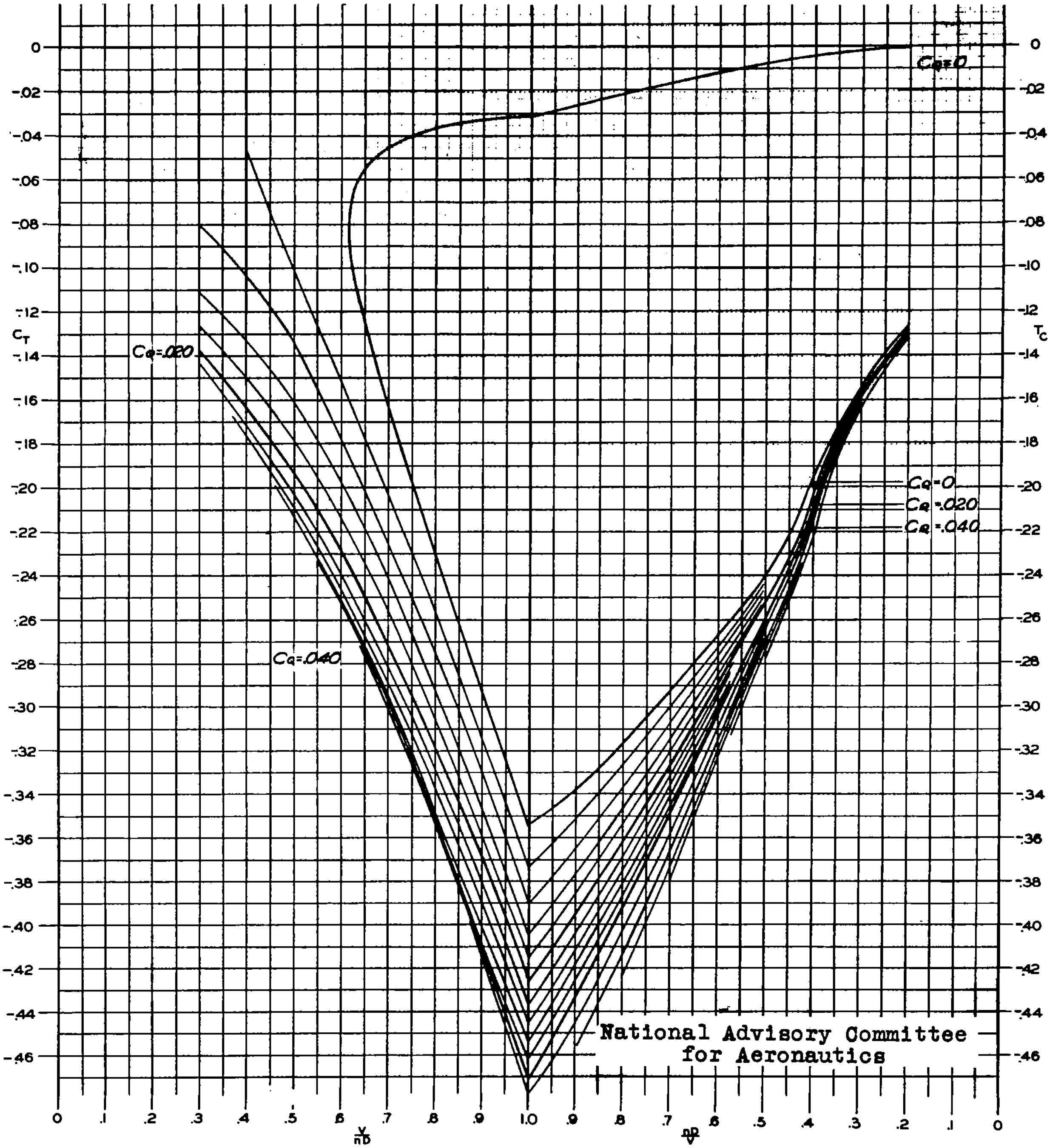


Figure 9.- Negative thrust coefficients at constant torque coefficients for the eight-blade, dual propeller.

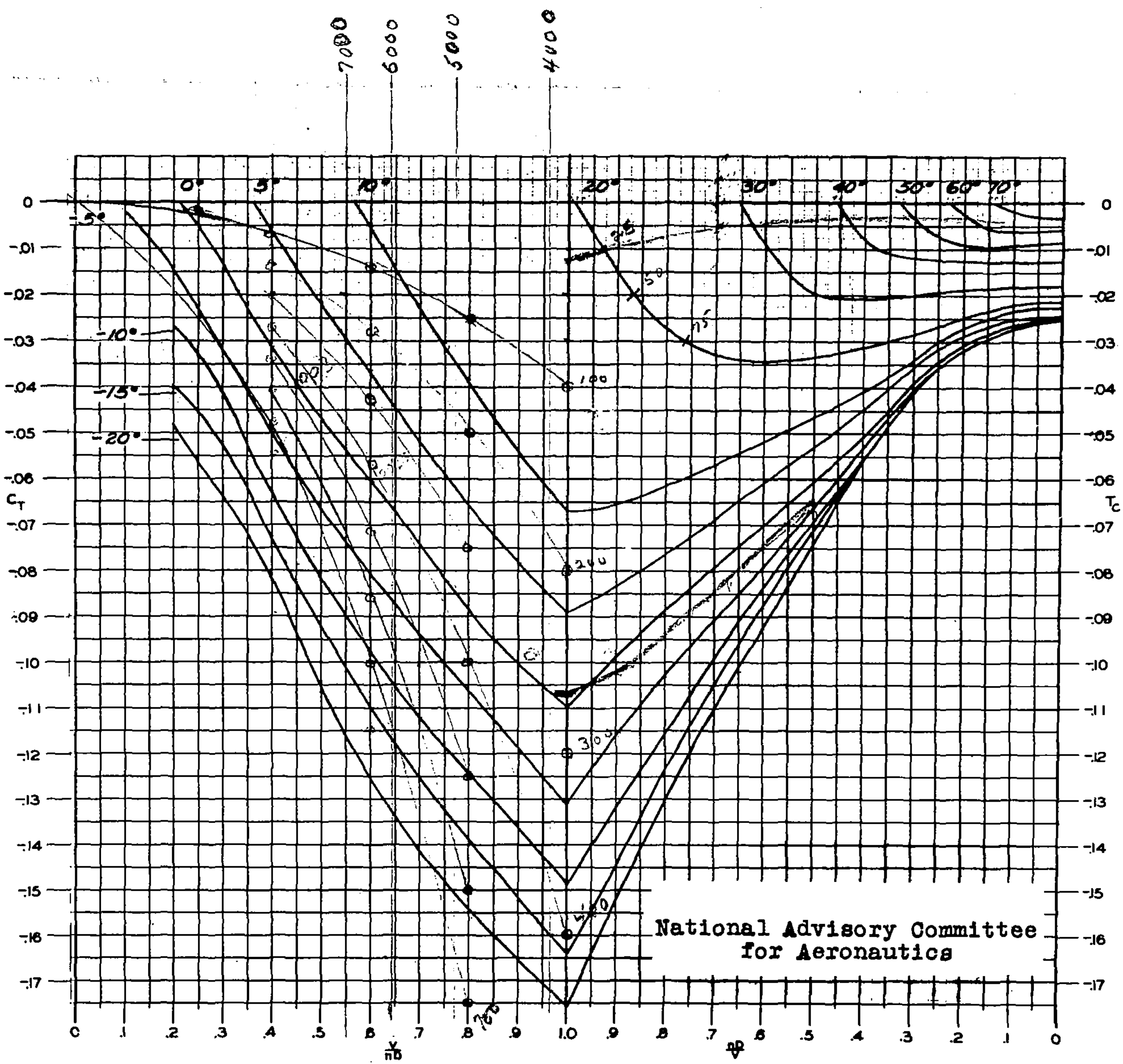


Figure 10.- Negative thrust coefficients at constant blade angles for the two-blade, single propeller.

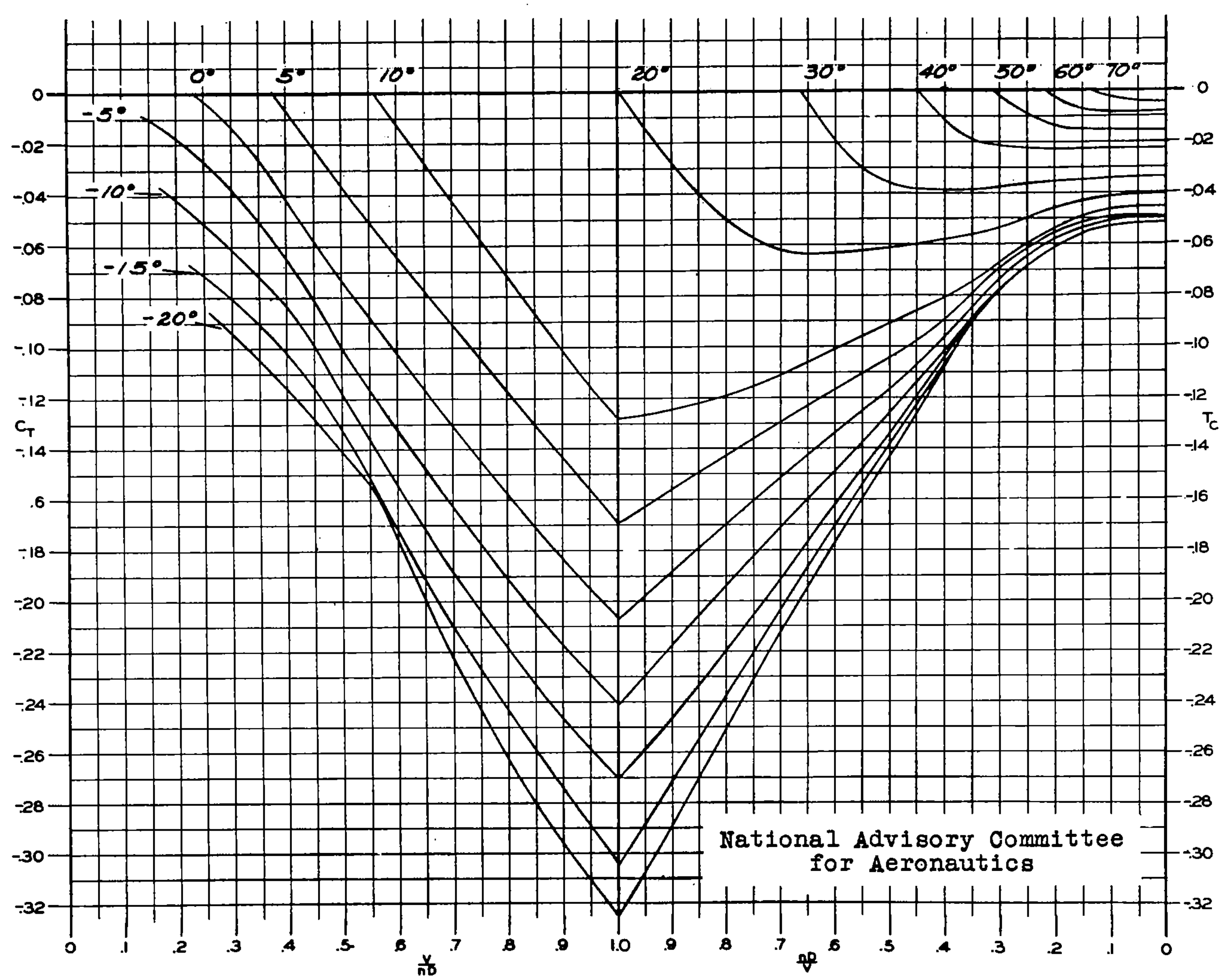


Figure 11.- Negative thrust coefficients at constant blade angles for the four-blade, single propeller.

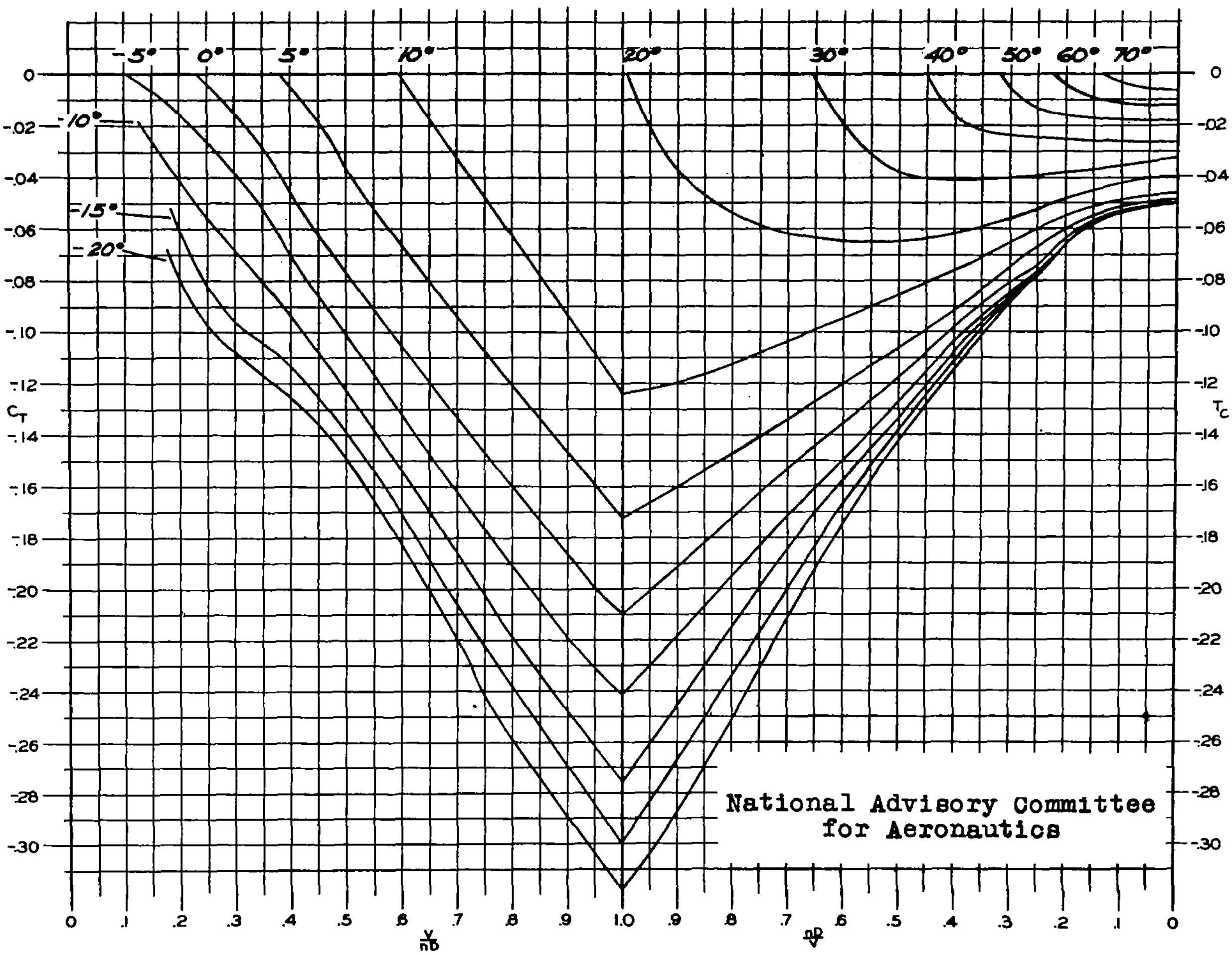


Figure 12.- Negative thrust coefficients at constant blade angles for the four-blade, dual propeller.

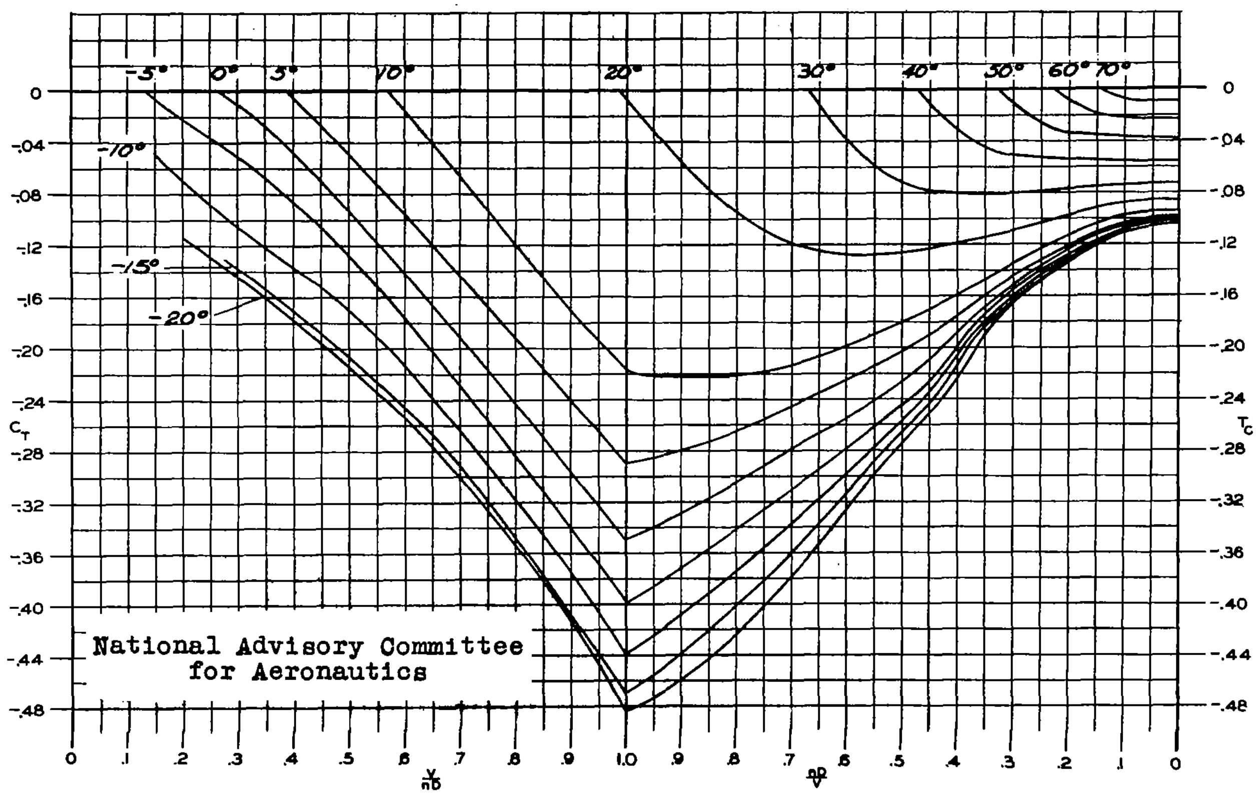


Figure 13.- Negative thrust coefficients at constant blade angles for the eight-blade, dual propeller.

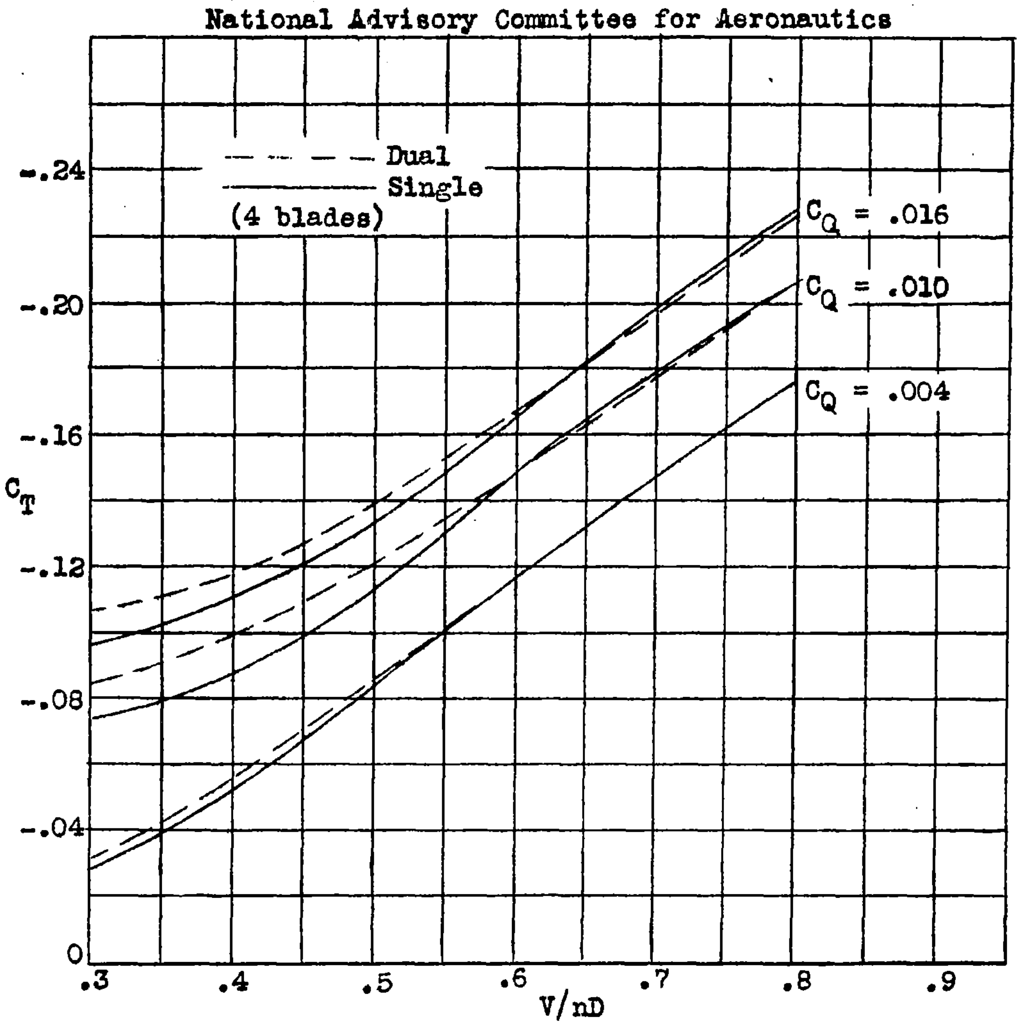


Figure 14.- Effect of type of rotation on negative thrust coefficient.

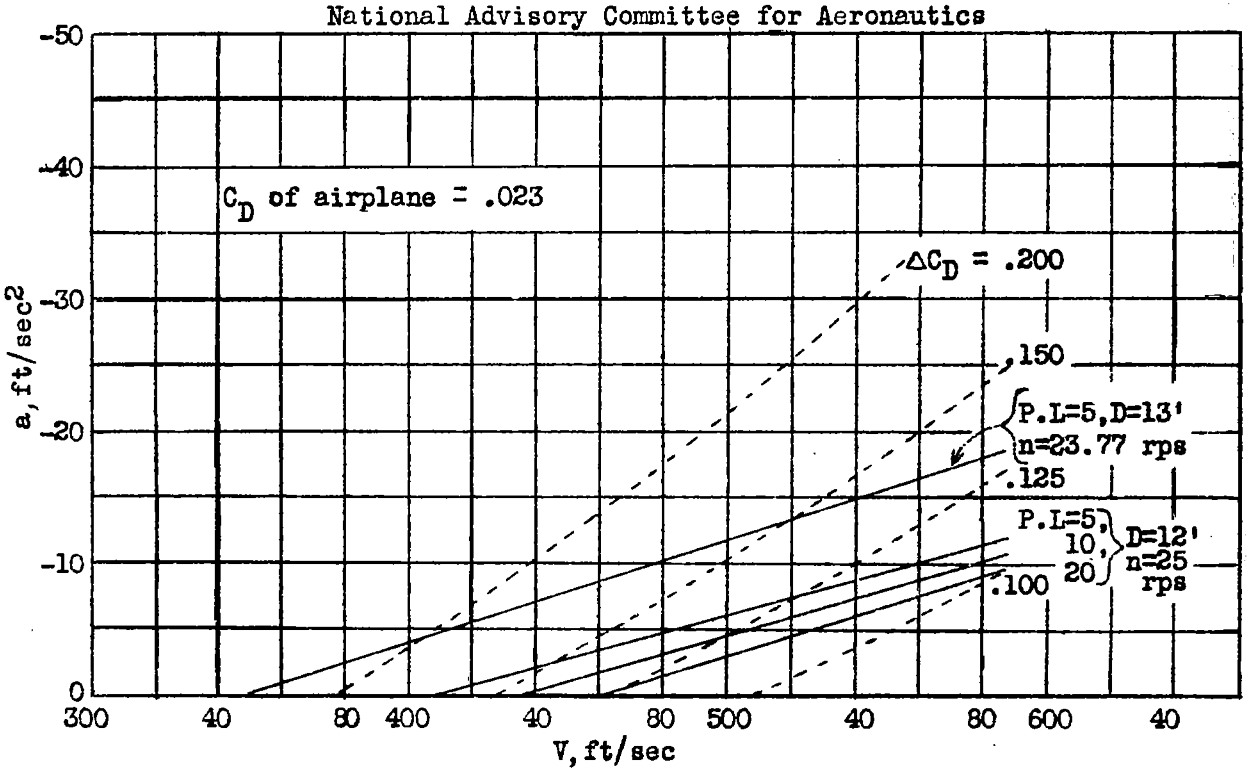


Figure 15.- The variation of deceleration with velocity for a dive bomber utilizing constant-speed reversed-pitch propellers and aerodynamic dive flaps while in a 60° dive.

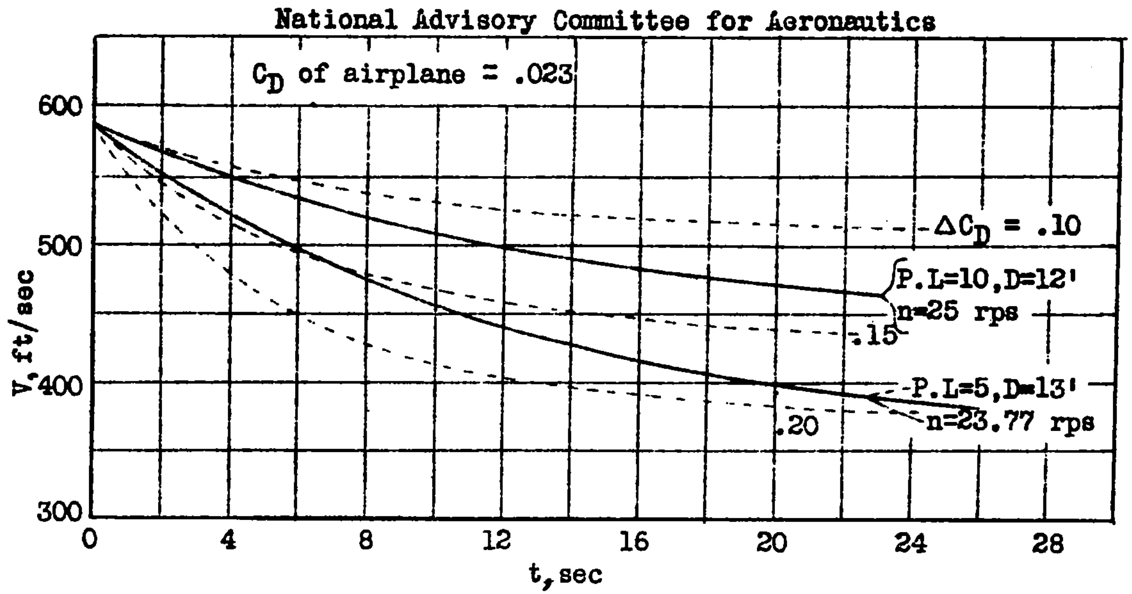


Figure 16.- The variation of velocity with time for a dive bomber utilizing constant-speed reversed-pitch propellers and aerodynamic dive flaps while in a 60° dive.

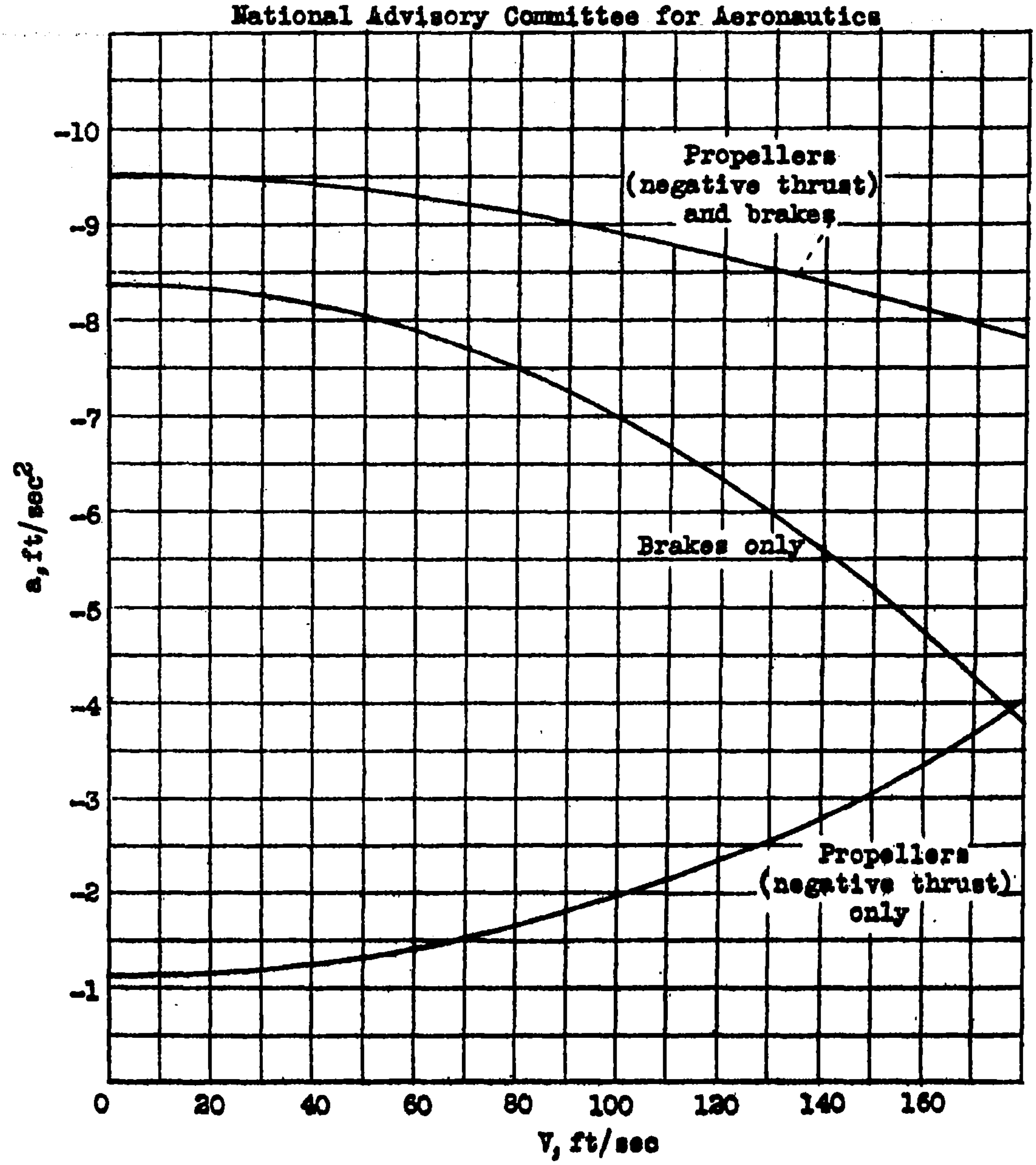


Figure 17.- The variation of deceleration with velocity for a heavy transport landing with wheel brakes and constant-speed reversed-pitch propellers.

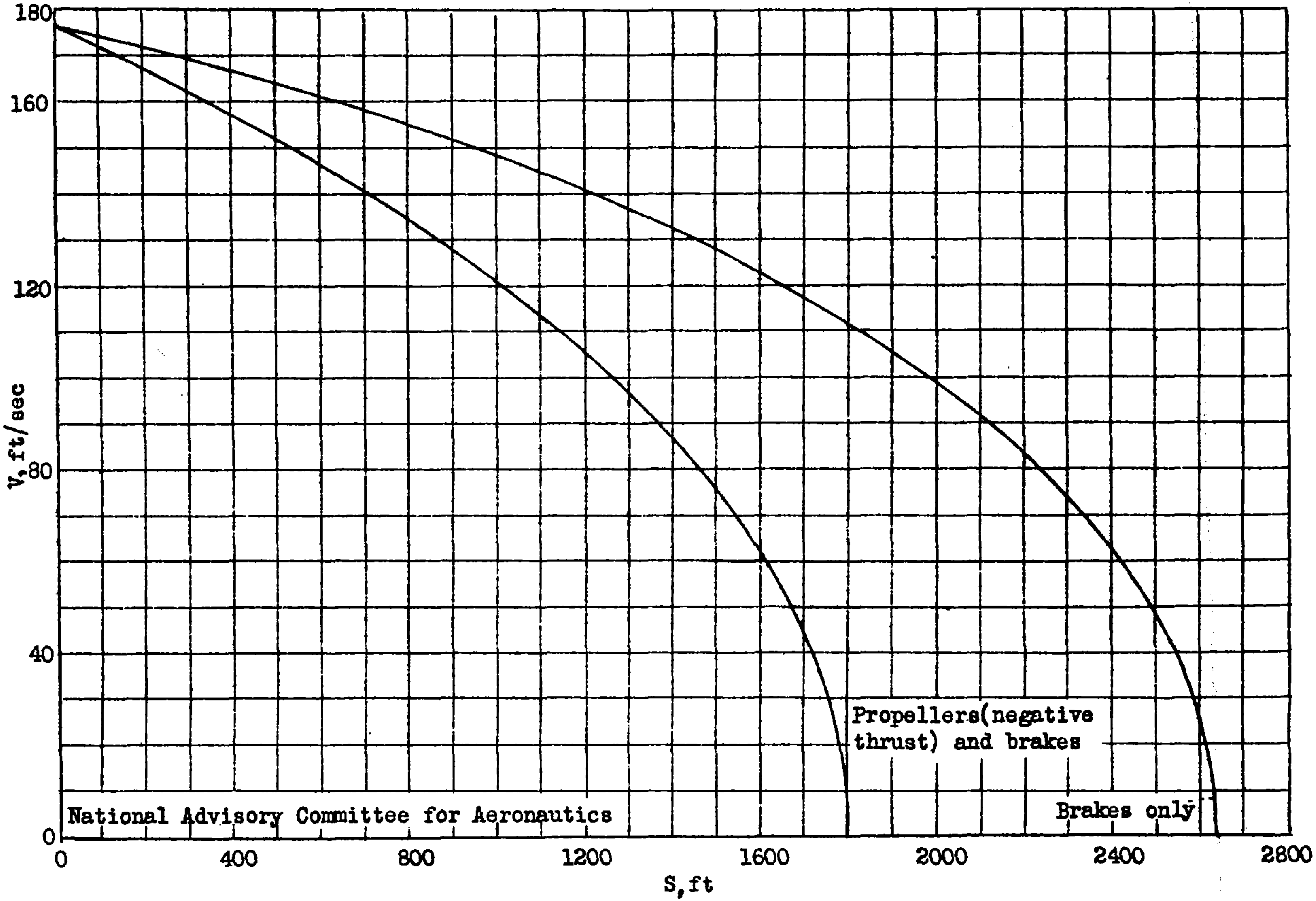


Figure 18.- The variation of velocity with distance for a heavy transport landing with wheel brakes and constant-speed reversed-pitch propellers.

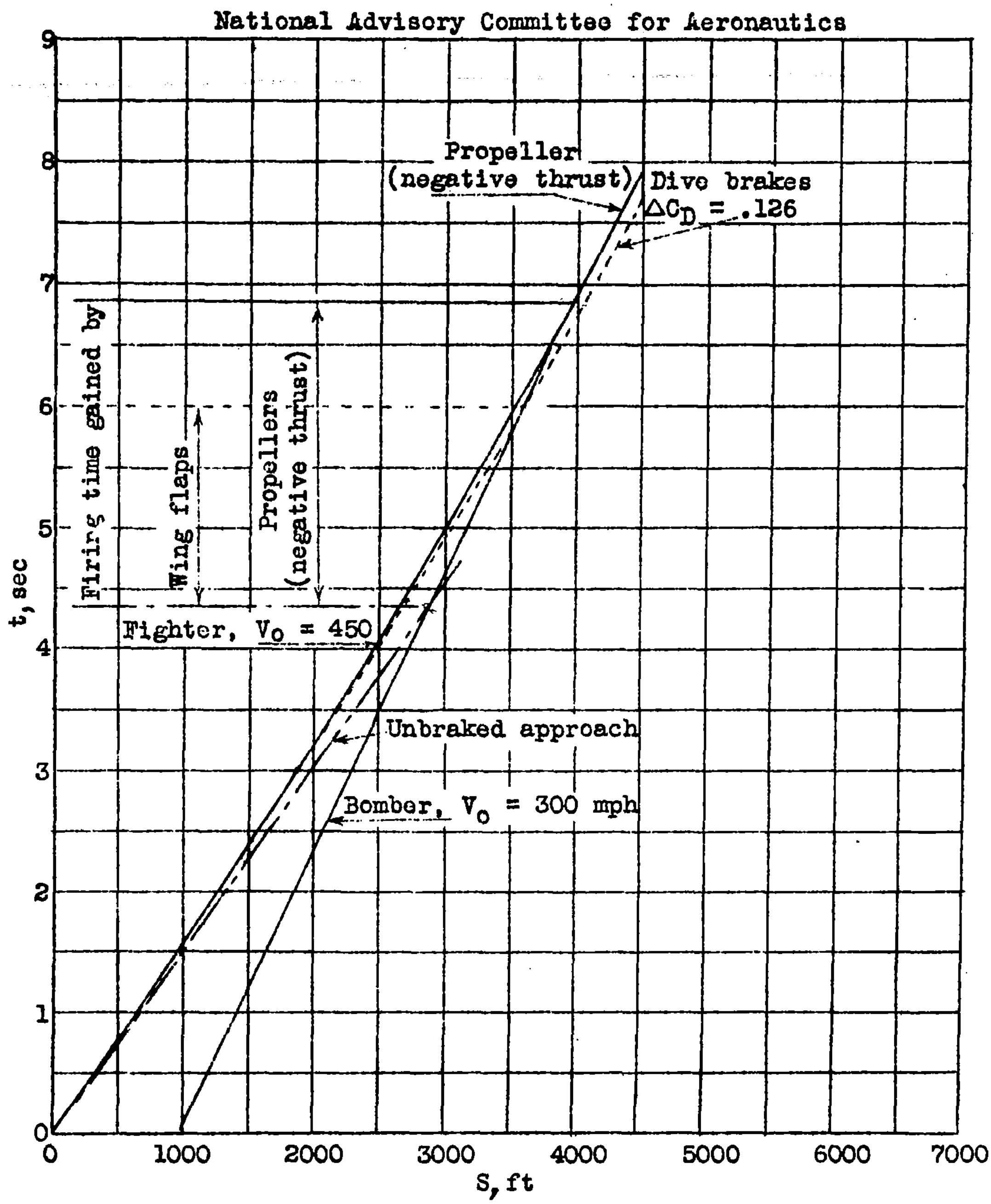


Figure 19.- The variation of time with distance for a fighter overtaking a bomber.